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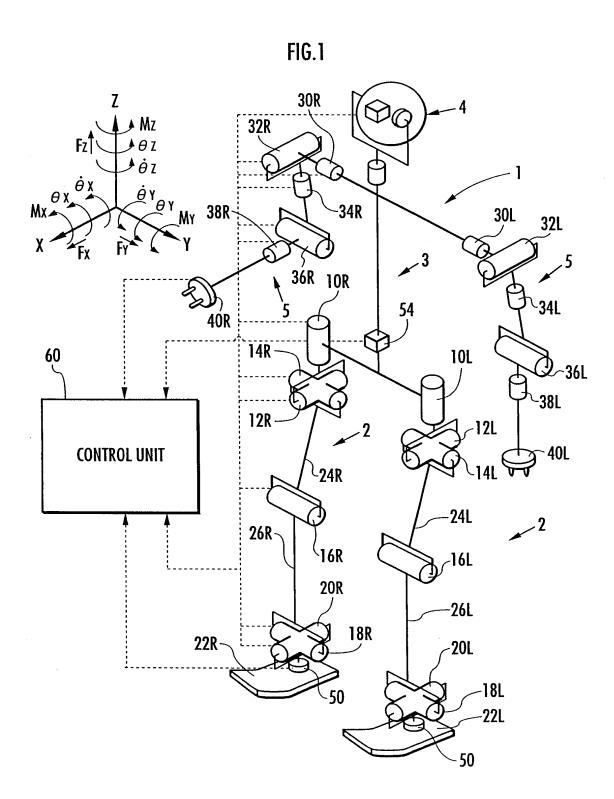


FIG.2

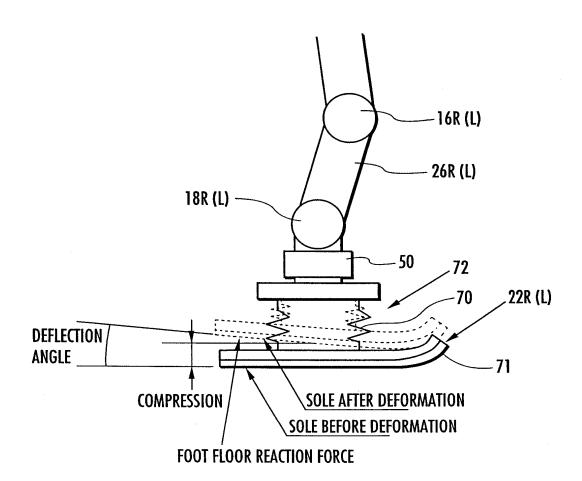
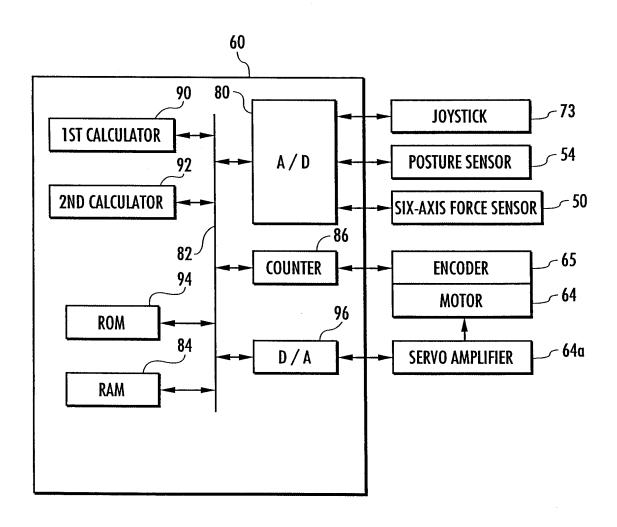
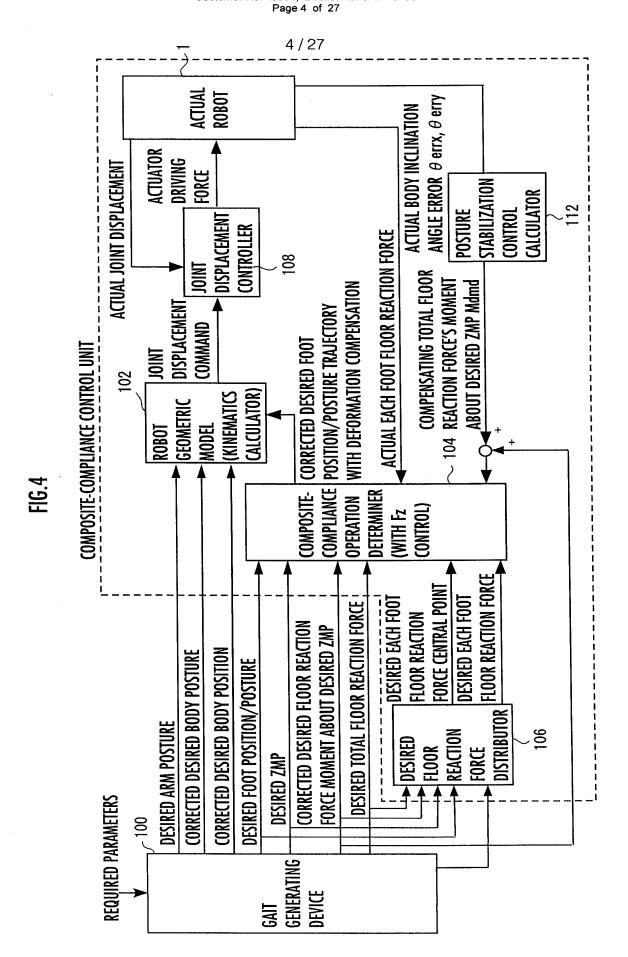


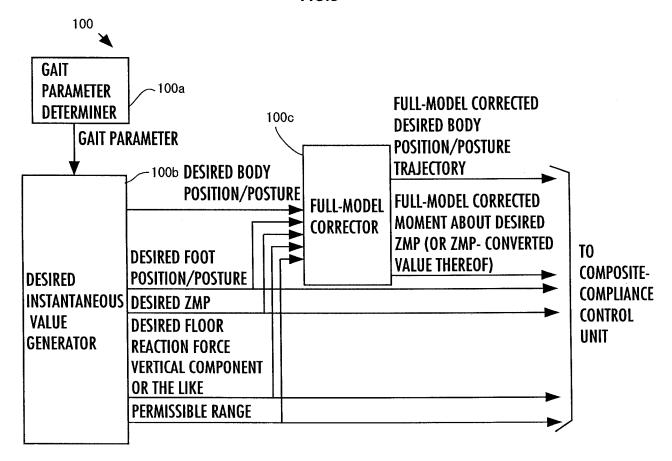
FIG.3



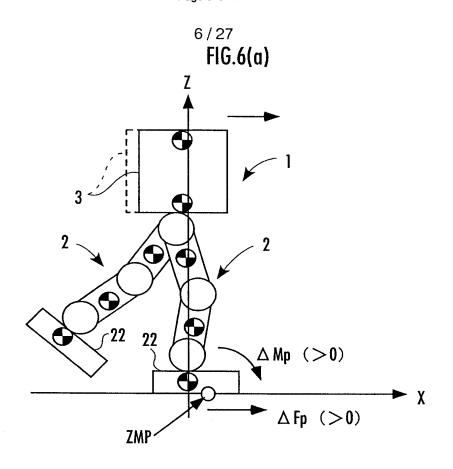


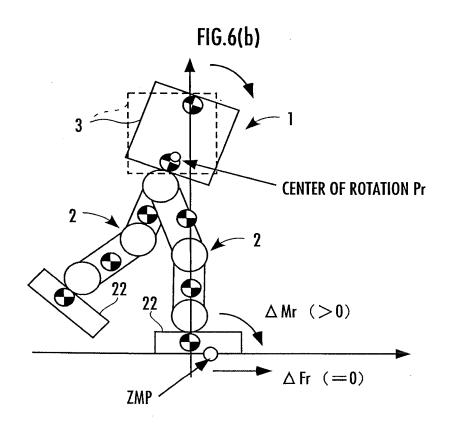
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FIG.5



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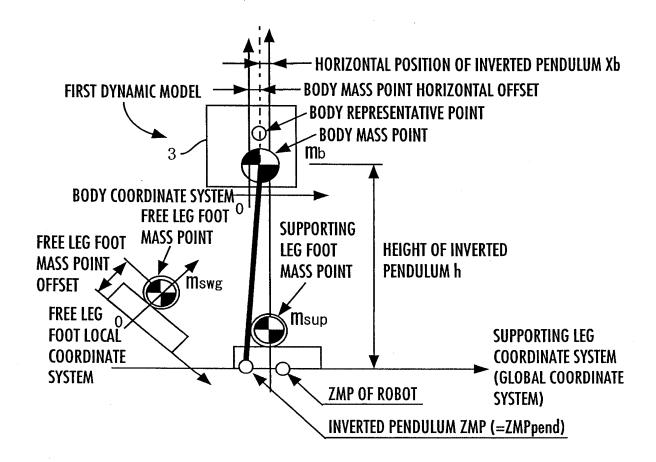


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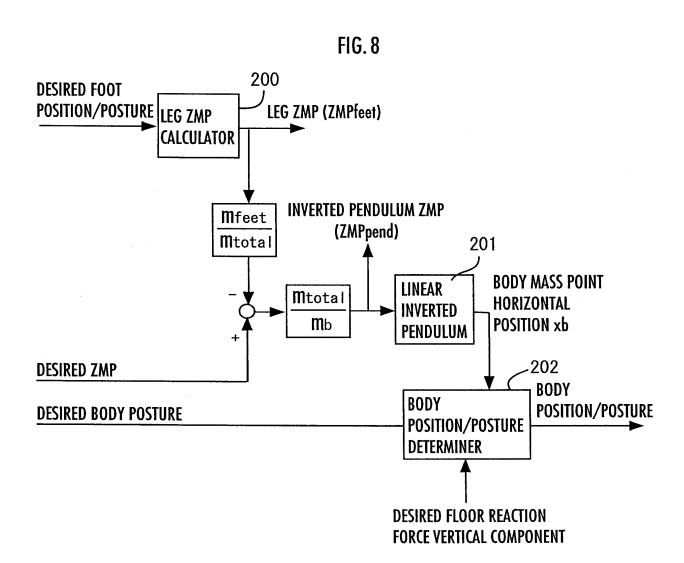
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FIG. 7

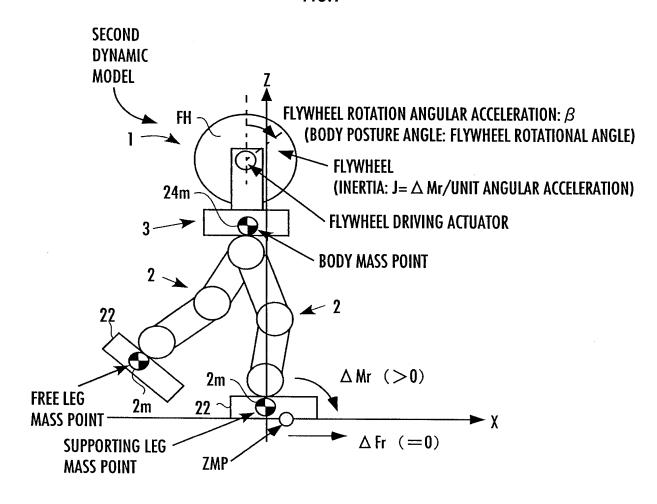


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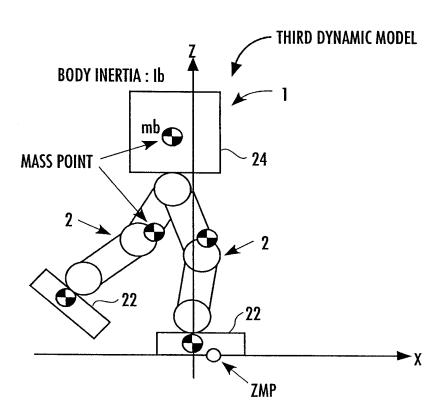
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FIG.9



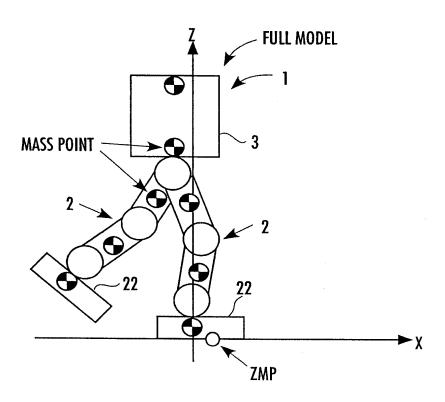
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FIG.10



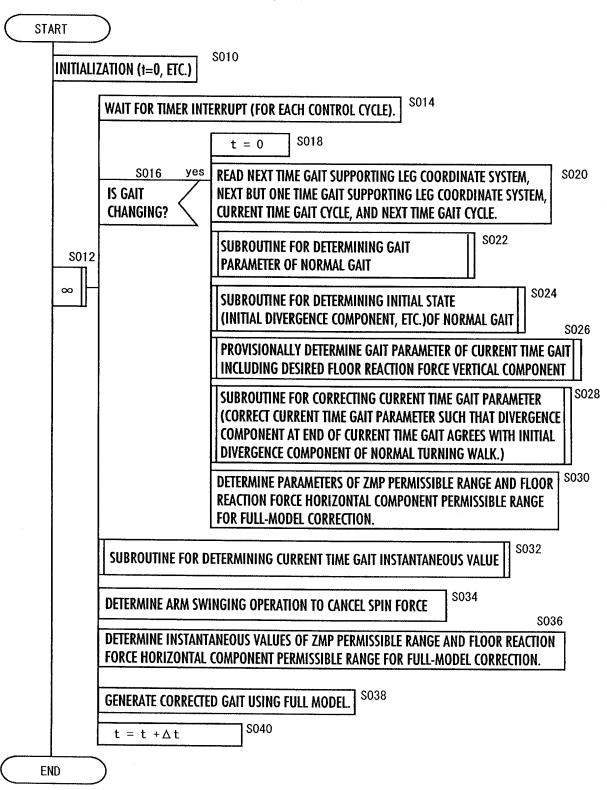
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FIG.11



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FIG.12



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FIG.13

S022 **ENTRY S100 DETERMINE FOOT TRAJECTORY PARAMETER** OF NORMAL GAIT. \$102 **DETERMINE REFERENCE BODY POSTURE TRAJECTORY** PARAMETER OF NORMAL GAIT. \$104 **DETERMINE ARM POSTURE TRAJECTORY PARAMETER** OF NORMAL GAIT. S106 **DETERMINE FLOOR REACTION FORCE VERTICAL** COMPONENT TRAJECTORY PARAMETER OF NORMAL GAIT. **S108 DETERMINE FLOOR REACTION FORCE HORIZONTAL** COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] OF NORMAL GAIT. \$110 **DETERMINE ZMP TRAJECTORY PARAMETER** OF NORMAL GAIT. **S112** REDEFINE INITIAL TIME TS AND ONE-STEP CYCLE Tayo OF NORMAL GAIT. RETURN

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FIG.14

ENTRY

S024

S200-1

DETERMINE FIRST MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF NORMAL TURNING GAIT PARAMETER BY USING FIRST MODEL AND DETERMINE FIRST MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xs1, Vxs1, ω bs1, ZMPrecpeek1).

S200-2

USING SECOND MODEL, TAKE (Xs1, Vxs1, ω bs1, ZMPrecpeek1) AS SEARCH INITIAL VALUES, AND SEARCH FOR SECOND MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE SECOND MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xs2, Vxs2, ω bs2, ZMPrecpeek2).

S200-n

USING n-TH MODEL, TAKE (Xsm, Vxsm, ω bsm, ZMPrecpeekm)(WHERE m=n-1) AS SEARCH INITIAL VALUES, AND SEARCH FOR n-TH MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE n-TH MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xsn, Vxsn, ω bsn, ZMPrecpeekn).

S204

BASED ON n-TH MODEL NORMAL TURNING GAIT, DETERMINE n-TH MODEL INITIAL BODY POSITION, VELOCITY, POSTURE ANGLE, ANGULAR VELOCITIES (X0n, Vx0n, θ b0n, ω b0n), AND INITIAL BODY VERTICAL POSITION/VELOCITY (ZOn, VzOn) AT ORIGINAL INITIAL TIME O.

DETERMINE n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] BY USING THE FOLLOWING EXPRESSION:

 $q[0] = X0n + Vx0n / \omega 0$

S224

S222

DETERMINE q", WHICH DENOTES VALUE OF n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT, AND DETERMINE (ZO", VzO"), WHICH DENOTE VALUES OF n-TH MODEL INITIAL BODY VERTICAL POSITION/VELOCITY OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT.

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FIG.15

S200-1 **ENTRY** \$250 DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE $\, heta$ bs, and arm posture on the basis of normal turning gait parameter PROVISIONALLY DETERMINE FIRST MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xs1, Vxs1, ω bs1, ZMPrecpeek1). S256 DETERMINE FIRST MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zs1, Vzs1). USING FIRST DYNAMIC MODEL, GENERATE FIRST MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeek1, TAKING θ bs1,(Xs1, Vxs1, ω bs1), (Zs1,Vzs1) AS INITIAL STATES OF BODY. S260 CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xe1, Vxe1, θ be1, ω be1). S254 S262 BOUNDARY CONDITION ERRORS (errx, errv, err θ , err ω) = (Xs1, Vxs1, θ bs1, ω bs1)-(Xe1, Vxe1, θ be1, ω be1) ∞ S264 LEAVE REPETITION LOOP. ARE ALL errx, erry, err θ b, AND errωb WITHIN PERMISSIBLE RANGES? DETERMINE A PLURALITY OF CANDIDATES (Xs1+ Δ Xs, Vxs1, ω bs1, ZMPrecpeek1), **S266** (Xs1, Vxs1+ \triangle Vxs, ω bs1, ZMPrecpeek1), (Xs1, Vxs1, ω bs1+ \triangle ω bs. ZMPrecpeek1). (Xs1, Vxs1, ωbs1, ZMPrecpeek1+ △ ZMPrecpeek) IN THE VICINITY OF (Xs1, Vxs1, ω bs1, ZMPrecpeek1), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE. S268 DETERMINE NEW CANDIDATES (Xs1, Vxs1, ω bs1, ZMPrecpeek1) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xs1, Vxs1, ω bs1, ZMPrecpeek1) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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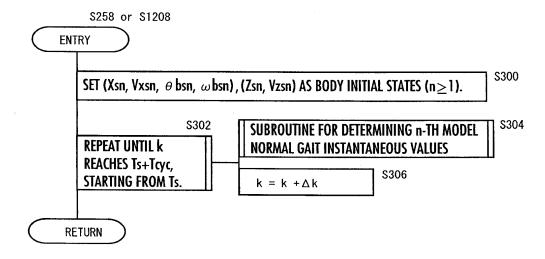
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FIG. 16

S202-n(n≥2) **ENTRY** \$1200 DETERMINE INITIAL STATES (STATES AT INITIAL TIME T_s) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE θ bs, and arm posture on the basis of normal turning gait parameter. SUBSTITUTE (Xsm, Vxsm, ω bsm, ZMPrecpeekm)(WHERE m=n-1) INTO n-TH MODEL INITIAL (AT Ts) BODY S1202 HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xsn, Vxsn, ω bsn, ZMPrecpeekn). S1206 DETERMINE n-TH MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zsn, Vzsn). \$1208 USING n-TH DYNAMIC MODEL, GENERATE n-TH MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeekn, TAKING θ bsn,(Xsn, Vxsn, ω bsn), (Zsn, Vzsn) AS INITIAL STATES OF BODY. \$1210 CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xen, Vxen, θ ben, ω ben). S1212 BOUNDARY CONDITION ERRORS (errx, errv, err θ , err ω) S1204 = (Xsn, Vxsn, θ bsn, ω bsn)-(Xen, Vxen, θ ben, ω ben) S1214 yes ∞ LEAVE REPETITION LOOP. ARE ALL errx, errv, err θ b, AND err ω b WITHIN PERMISSIBLE RANGES? S1216 DETERMINE A PLURALITY OF CANDIDATES (Xsn+ \triangle Xs, Vxsn, ω bsn, ZMPrecpeekn), (Xsn, Vxsn+ \triangle Vxs, ω bsn, ZMPrecpeekn), (Xsn, Vxsn, ω bsn+ \triangle ω bs, ZMPrecpeekn), (Xsn, Vxsn, ωbsn, ZMPrecpeekn+ Δ ZMPrecpeek) IN THE VICINITY OF (Xsn, Vxsn, ω bsn, ZMPrecpeekn), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING EACH OF THEM AS DESCRIBED ABOVE. **S1218** DETERMINE NEW CANDIDATES (Xsn, Vxsn, ω bsn, ZMPrecpeekn) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xsn, Vxsn, ω bsn, ZMPrecpeekn) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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FIG.17



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FIG.18

S304 or S804

ENTRY

DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT TIME **k** ON THE BASIS OF GAIT PARAMETER.

\$400

DETERMINE DESIRED ZMP AT TIME **k** ON THE BASIS OF GAIT PARAMETER.

S402

DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE, AND DESIRED ARM POSTURE AT TIME k ON THE BASIS OF GAIT PARAMETER.

S404

CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFY DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.

S406

CALCULATE BODY VERTICAL POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.

S408

DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin, Fxmax] AT TIME k ON THE BASIS OF GAIT PARAMETER.

S410

S412

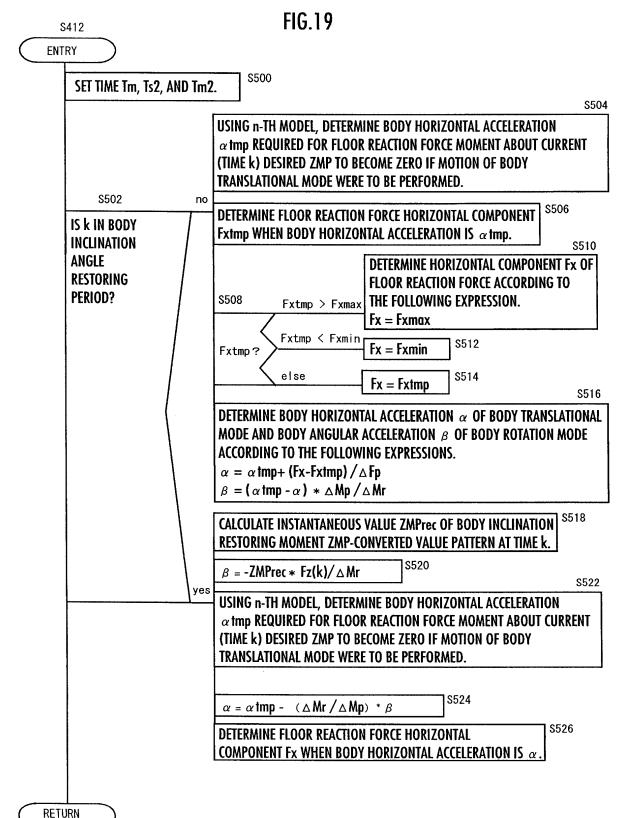
DETERMINE BODY HORIZONTAL ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION BY USING n-TH MODEL ($n \ge 1$) Such that floor reaction force moment about desired ZMP Becomes zero. Specifically, determine body horizontal acceleration and Body Posture angular acceleration such that floor reaction force horizontal component fx does not exceed [fxmin, fxmax]

AND THAT BODY POSTURE ANGULAR ACCELERATION IS GENERATED ACCORDING TO ZMPrec PATTERN IN BODY INCLINATION ANGLE RESTORING PERIOD.

S414

INTEGRATE BODY HORIZONTAL ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE BODY HORIZONTAL VELOCITY AND BODY POSTURE ANGULAR VELOCITY. INTEGRATE THE CALCULATION RESULTS TO DETERMINE BODY HORIZONTAL POSITION AND BODY POSTURE.

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FIG.20

	110.20	
;	S026	
(E	NTRY	
	DETERMINE FOOT TRAJECTORY PARAMETER	600
	OF CURRENT TIME GAIT.	
		I S602
	DETERMINE REFERENCE BODY POSTURE TRAJECTORY PARAMETER OF CURRENT TIME GAIT.	0002
	DETERMINE ARM POSTURE TRAJECTORY PARAMETER OF CURRENT TIME GAIT.	S604
		•
	DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT	S606
	TRAJECTORY PARAMETER OF CURRENT TIME GAIT.	
		1 S608
	DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT LIMIT RANGE [Fxmin, Fxmax]	3000
	OF CURRENT TIME GAIT.]
		l S610
	PROVISIONALLY DETERMINE ZMP TRAJECTORY PARAMETER OF CURRENT TIME GAIT.	3010
		1 0040
	SET BODY INCLINATION ANGLE RESTORING PERIOD [Ta, Tb]	S612
F	RETURN)	

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FIG.21

S028

ENTRY

USING FIRST MODEL, DETERMINE (a1, ZMPrecpeeka1, ZMPrecpeekb1), WHICH ARE VALUES OF (a, ZMPrecpeeka, ZMPrecpeekb) FOR FIRST MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF CURRENT TIME GAIT PARAMETER.

S700-1

USING SECOND MODEL, TAKE (a1, ZMPrecpeeka1, ZMPrecpeekb1) AS SEARCH INITIAL VALUES AND DETERMINE (a2, ZMPrecpeeka2, ZMPrecpeekb2), WHICH ARE VALUES OF (a, ZMPrecpeeka, ZMPrecpeekb) FOR SECOND MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.

S700-2

S700-n

USING n-TH MODEL, TAKE (am, ZMPrecpeekam, ZMPrecpeekbm)(WHERE m=n-1) AS SEARCH INITIAL VALUES AND DETERMINE (an, ZMPrecpeekn, ZMPrecpeekbn), WHICH ARE VALUES OF (a, ZMPrecpeeka, ZMPrecpeekb) FOR n-TH MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.

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FIG.22

S700-1

ENTRY

S750

PROVISIONALLY DETERMINE FIRST MODEL ZMP CORRECTION PARAMETER CANDIDATE at and body inclination restoring moment zmp-converted value peak value candidates (zmprecpeekat, zmprecpeekbt).

S754

S756

CALCULATE FIRST MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING FIRST MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP TRAJECTORY PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE a1, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeeka1, ZMPrecpeekb1). AND OTHER CURRENT TIME GAIT PARAMETER.

DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k]
ACCORDING TO THE FOLLOWING EXPRESSION FROM BODY POSITION/VELOCITY (Xe1, Ve1)
AT TERMINATING END OF CURRENT TIME GAIT:

 $q01[k] = Xe1 + Vxe1 / \omega 0$

DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR error according to the following expression:

errq = q01[k] - q''

S758

TERMINAL BODY INCLINATION ANGLE ERROR θ berr

= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE

- FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGLE

TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR ω berr

= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY

S762

- FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGULAR VELOCITY

yes

S752

∞

ARE ALL errq, θ berr, AND ω berr WITHIN PERMISSIBLE RANGES?

LEAVE REPETITION LOOP.

S764

S760

DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES ($a1 + \Delta a$, ZMPrecpeeka1, ZMPrecpeekb1),

- (a1, ZMPrecpeeka1 + △ZMPrecpeeka, ZMPrecpeekb1), AND
- (a1, ZMPrecpeeka1, ZMPrecpeekb1 + △ ZMPrecpeekb) IN THE VICINITY OF
- (a1, ZMPrecpeeka1, ZMPrecpeekb1), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.

DETERMINE NEW PARAMETER CANDIDATES (a1, ZMPrecpeeka1, ZMPrecpeekb1) ON THE BASIS OF (a1, ZMPrecpeeka1, ZMPrecpeekb1) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

S766

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FIG.23

S700-n (n≥2)
ENTRY

S1700

SUBSTITUTE am AND (ZMPrecpeekam, ZMPrecpeekbm)(WHERE m=n-1) INTO n-TH MODEL ZMP CORRECTION PARAMETER CANDIDATE an AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeekan, ZMPrecpeekbn), RESPECTIVELY.

S1704

S1706

CALCULATE n-TH MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING n-TH MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE an, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeekan, ZMPrecpeekbn), AND OTHER CURRENT TIME GAIT PARAMETER.

DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k] FROM BODY HORIZONTAL POSITION/VELOCITY (Xen, Ven) AT TERMINATING END OF CURRENT TIME GAIT ACCORDING TO THE FOLLOWING EXPRESSION: $q0n[k] = Xen + Vxen / \omega 0$

DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR error according to the following expression:

S1708

errq = q0n[k] - q''

TERMINAL BODY INCLINATION ANGLE ERROR θ berr

= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE

– n-TH MODEL CURRENT TIME GAIT INITIAL BODY INCLINATION ANGLE TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR $\,\omega$ berr

- = n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY
 - n-TH MODEL CURRENT TIME GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY

\$1712 yes

LEAVE REPETITION LOOP.

__

S1702

ARE ALL errq, θ berr, AND ω berr WITHIN PERMISSIBLE RANGES?

S1714

S1710

DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (an+ \triangle a, ZMPrecpeekan, ZMPrecpeekbn), (an, ZMPrecpeekan+ \triangle ZMPrecpeekbn, AND (an, ZMPrecpeekan, ZMPrecpeekbn+ \triangle ZMPrecpeekb) IN THE VICINITY OF (an, ZMPrecpeekan, ZMPrecpeekbn), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.

DETERMINE NEW PARAMETER CANDIDATES (an, ZMPrecpeekan, ZMPrecpeekbn) ON THE BASIS OF (an, ZMPrecpeekan, ZMPrecpeekbn) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

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FIG.24

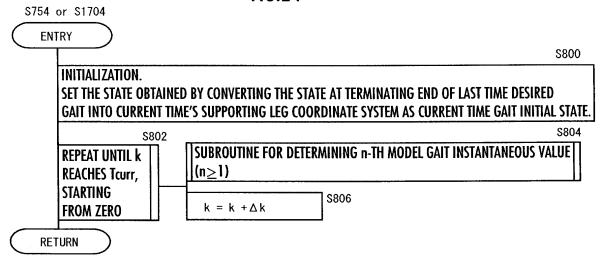


FIG.25
BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE OF NORMAL GAIT (ZMPrec)

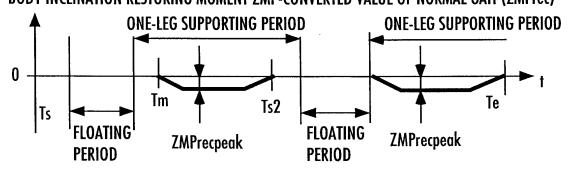
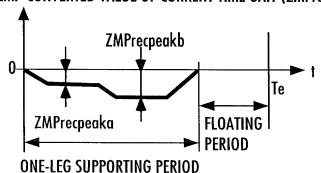


FIG.26

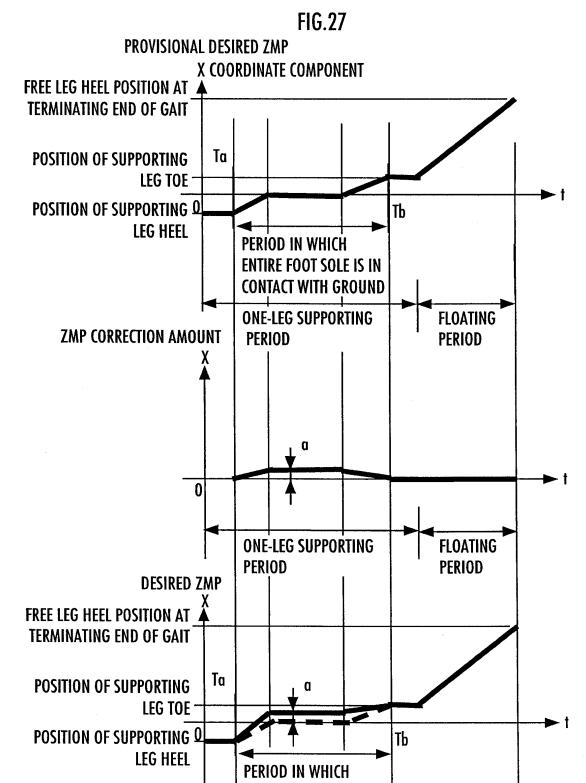
BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE OF CURRENT TIME GAIT (ZMPrec)



Title: "GATE GENERATING SYSTEM FOR MOBILE ROBOT (as amended)

First Named Inventor: Toru Takenaka National Stage of PCT/JP2005/002354 Customer No. 40854; Docket No. SAT-16750 Page 25 of 27

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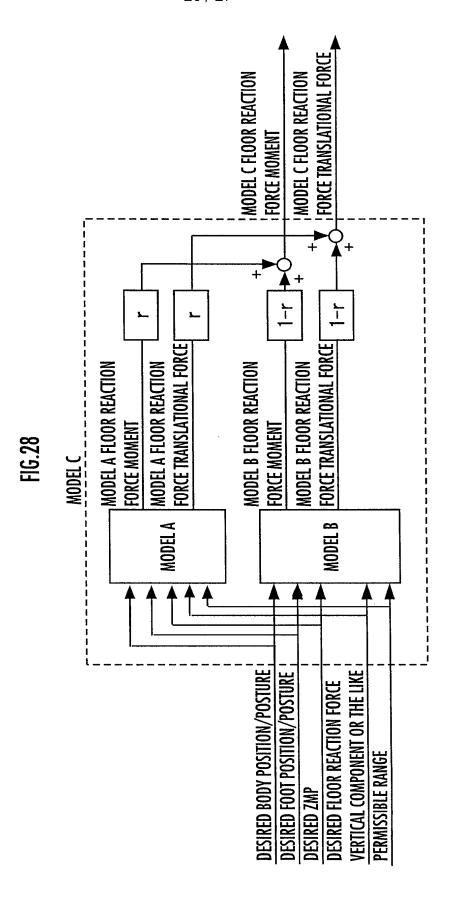
ENTIRE FOOT SOLE IS IN CONTACT WITH GROUND

ONE-LEG SUPPORTING

PERIOD

FLOATING

PERIOD



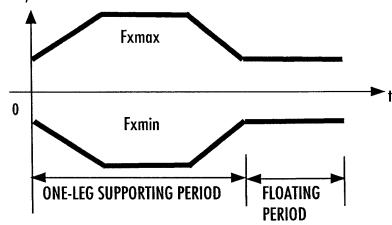
Title: "GATE GENERATING SYSTEM FOR MOBILE ROBOT (as amended)
First Named Inventor: Toru Takenaka

National Stage of PCT/JP2005/002354 Customer No. 40854; Docket No. SAT-16750 Page 27 of 27

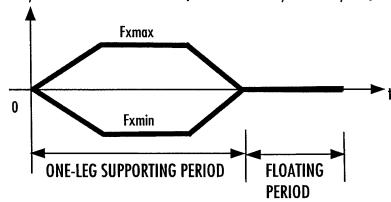
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FIG.29





Fxmin,Fxmax FOR m-TH MODEL (WHERE 1<m<n, ex. m=2,n=3)



Fxmin,Fxmax FOR n-TH MODEL (ex. n=3)

